Characterizing Impacts of High Temperature and Pressures in Oxy-Coal Combustion Systems

Department of Energy under Cooperative Agreement No. DE-FE0025168

For Energy and Environmental Solutions
REACTION ENGINEERING INTERNATIONAL

2018 NETL CO_2 Capture Technology Project Review Meeting

Omni William Penn Hotel; Pittsburgh, PA

August 14, 2018

Program Overview

Enabling Technologies for Advanced Oxy-Coal Combustion Systems

Characterizing Impacts of High Temperature and Pressures in Oxy-Coal Combustion Systems (HTHP)

September, 2015 – August 2018

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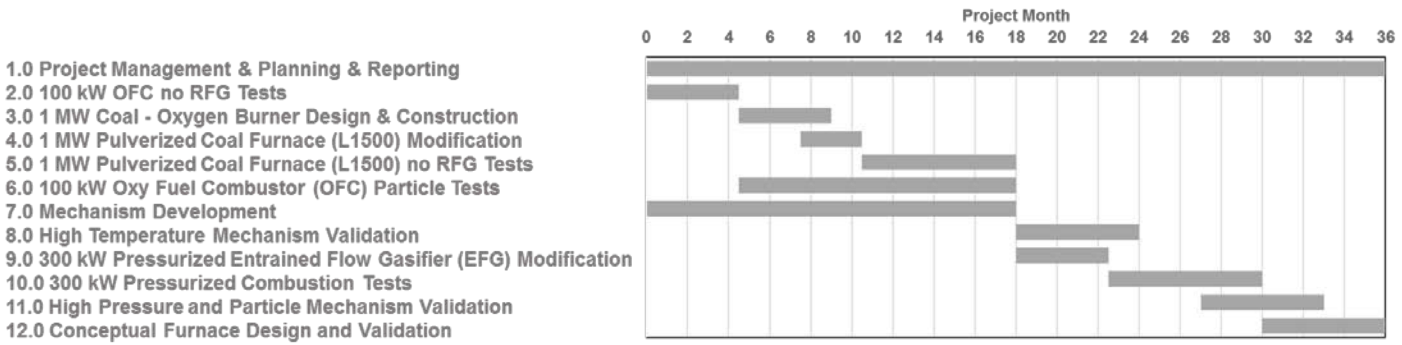
PRAXAIR

Jupiter Oxygen

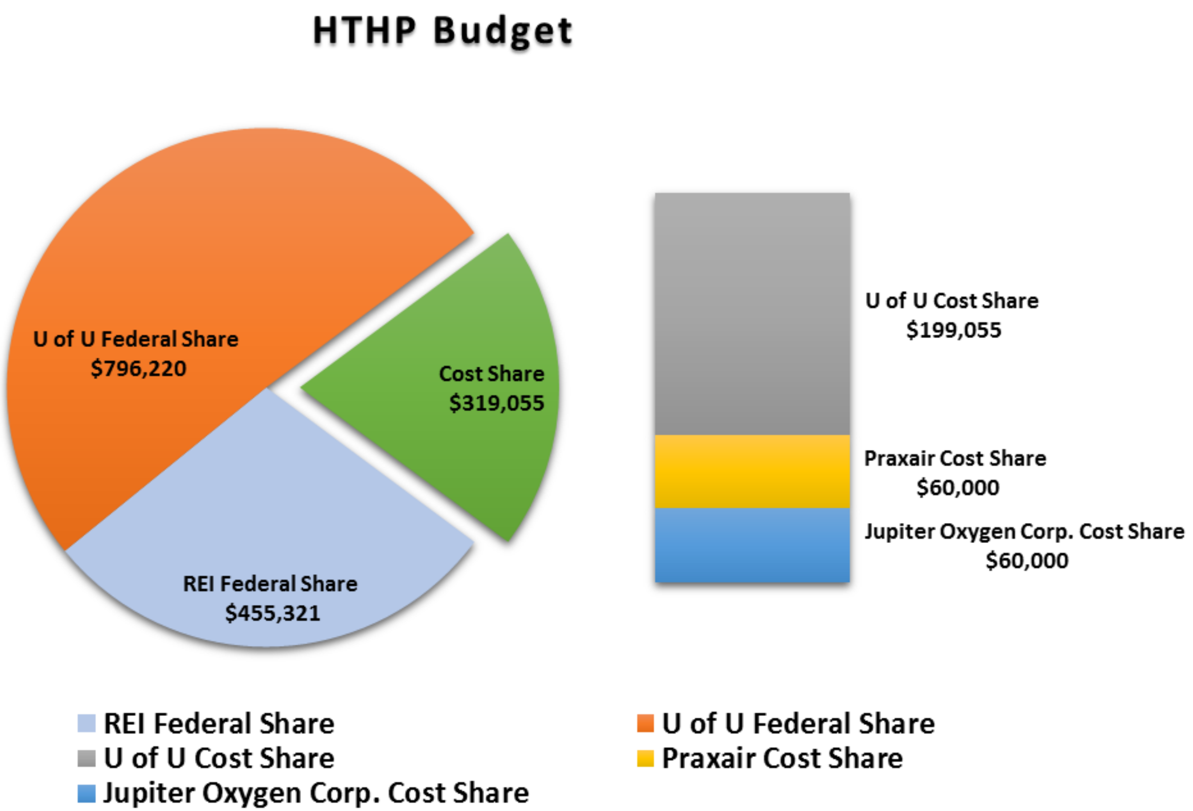
- Key second generation candidates for CO_2 capture include high temperature and pressurized oxy-firing of coal
- Promising technologies because of potential to increase efficiency, lower capital costs, avoid air ingress and reduce oxygen requirements
- Unquantified challenges exist in the practical utilization of these technologies

Timeline & Budget

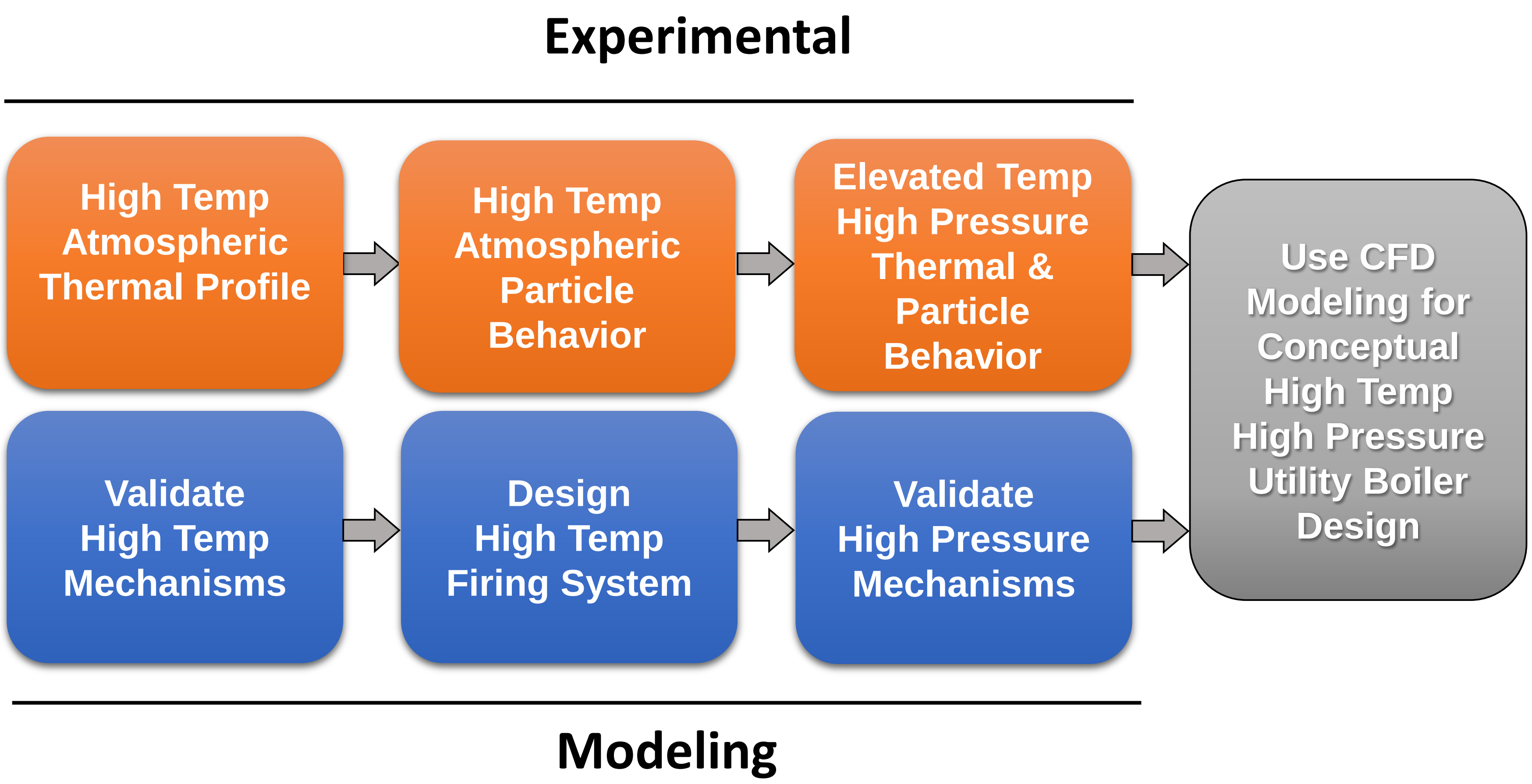


Total Budget
$1,570,596

Total Federal
$1,251,541



Program Approach



Technical Approach

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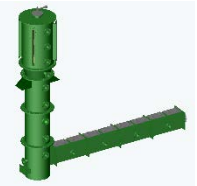
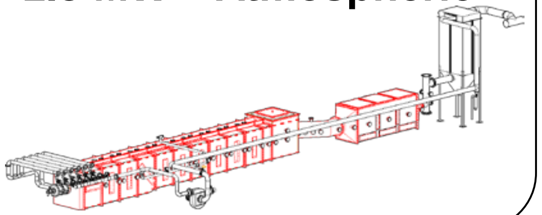
Experimental

High Temp (Minimum Recycle)

Oxy-fuel Combustor
100 kW – Atmospheric



L1500 Multi-fuel Furnace
1.5 MW – Atmospheric



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Modeling

Design High Temp Firing System

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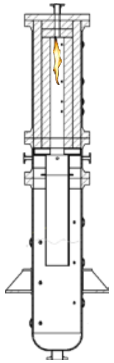
Experimental

Elevated Temperature & Pressurized (17 bar)

300 kW <u>Pressurized</u>
Entrained Flow Reactor



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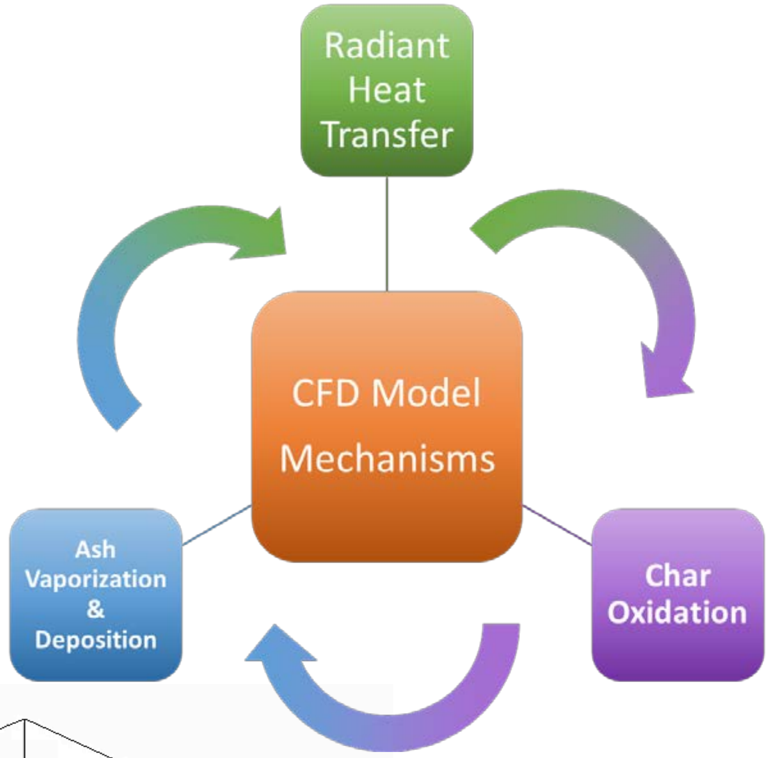
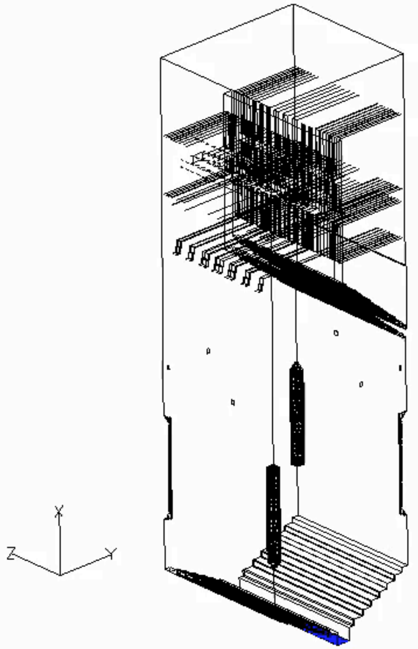
Modeling

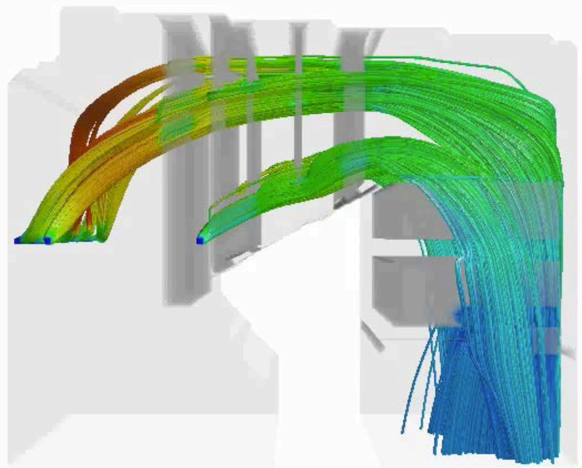
Design Pressurized Firing System

CFD Tools: GLACIER

- REI's in-house CFD software
- Developed specifically for application to solid fuel fired furnaces and boilers
- 3D, steady-state, turbulent flows
- Coupling between turbulent fluid mechanics, radiative and convective heat transfer, homogeneous and heterogeneous reactions
- Statistical description of particles including particle dispersion
- Pollutant formation kinetics for NO_x, SO_x, CO, Hg and fine particles
- Continually evolving including recent developments for atmospheric pressure and pressurized oxy-coal applications







100 kW Oxy-Fuel Combustor

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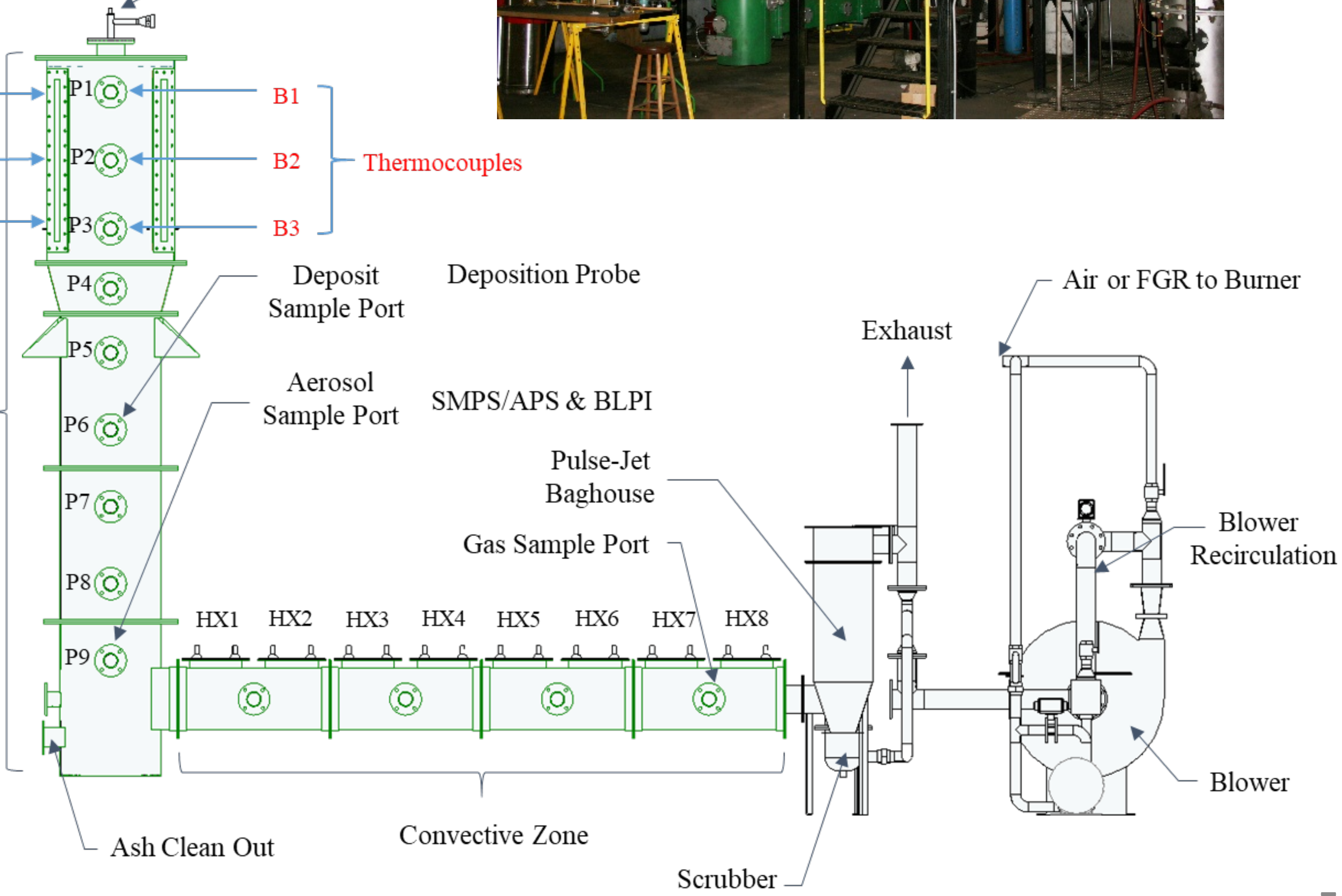
Specifications

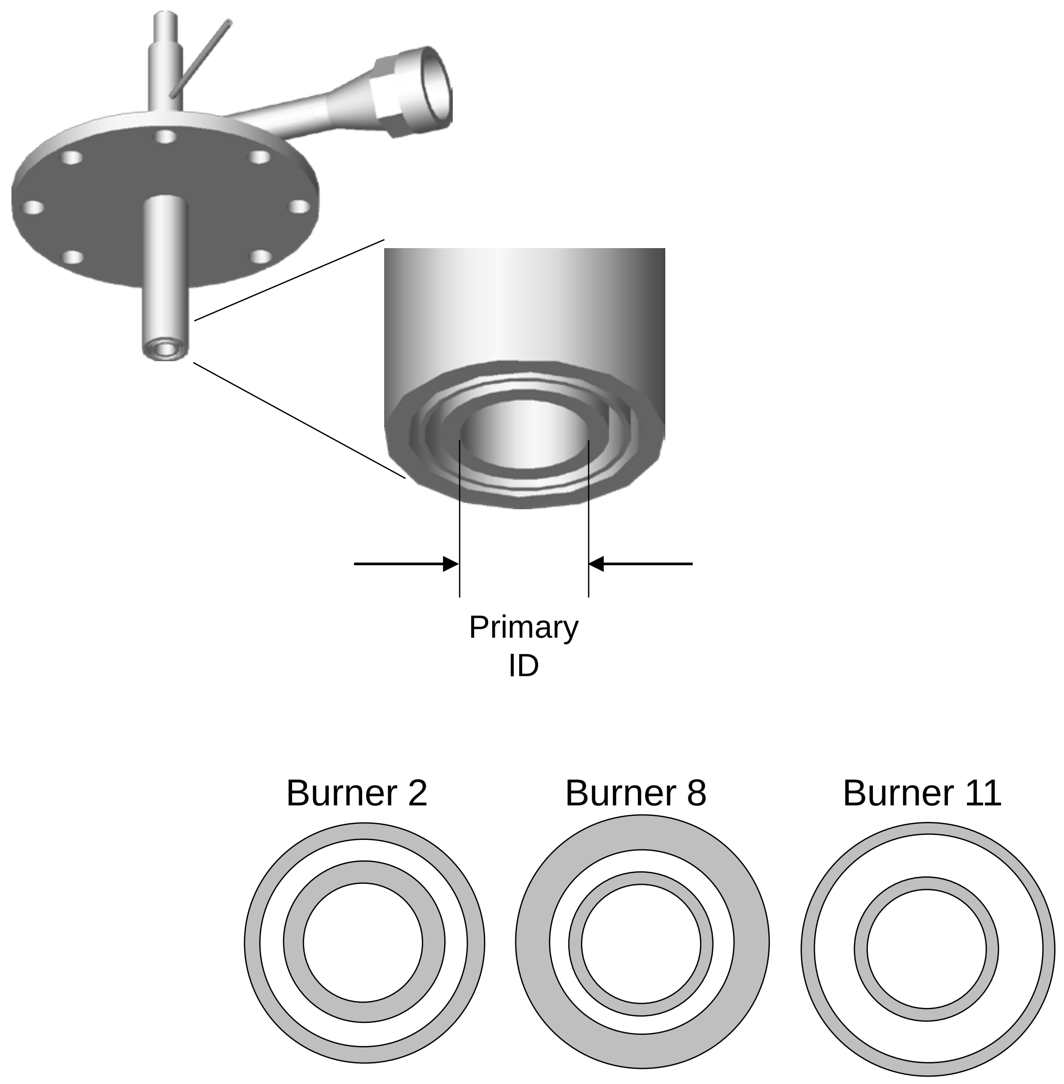
- 100 kW (0.25 MBtu/hr) Firing Rate
- Main Burner Zone 20 in x 48 in
- Quartz Windows for Optical Access of Flame
- Vertical Height 12.5 ft
- Horizontal Convective Section 12 ft

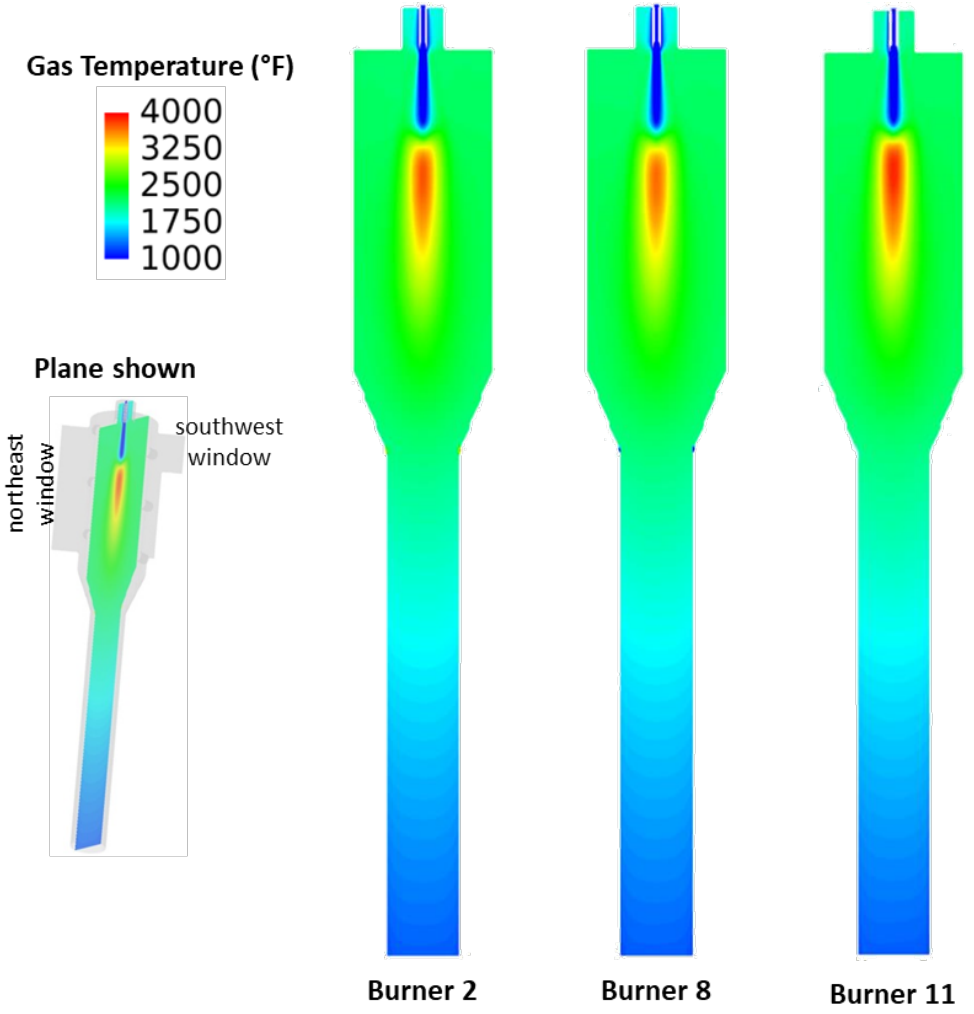
Research

- Ash Formation
  - Aerosols
  - Deposition
  - Trace Elements
- Sorbent Development
- Optical Diagnostics
  - Flame, Radiation & Flow Field



CFD Model Predictions (Validation)





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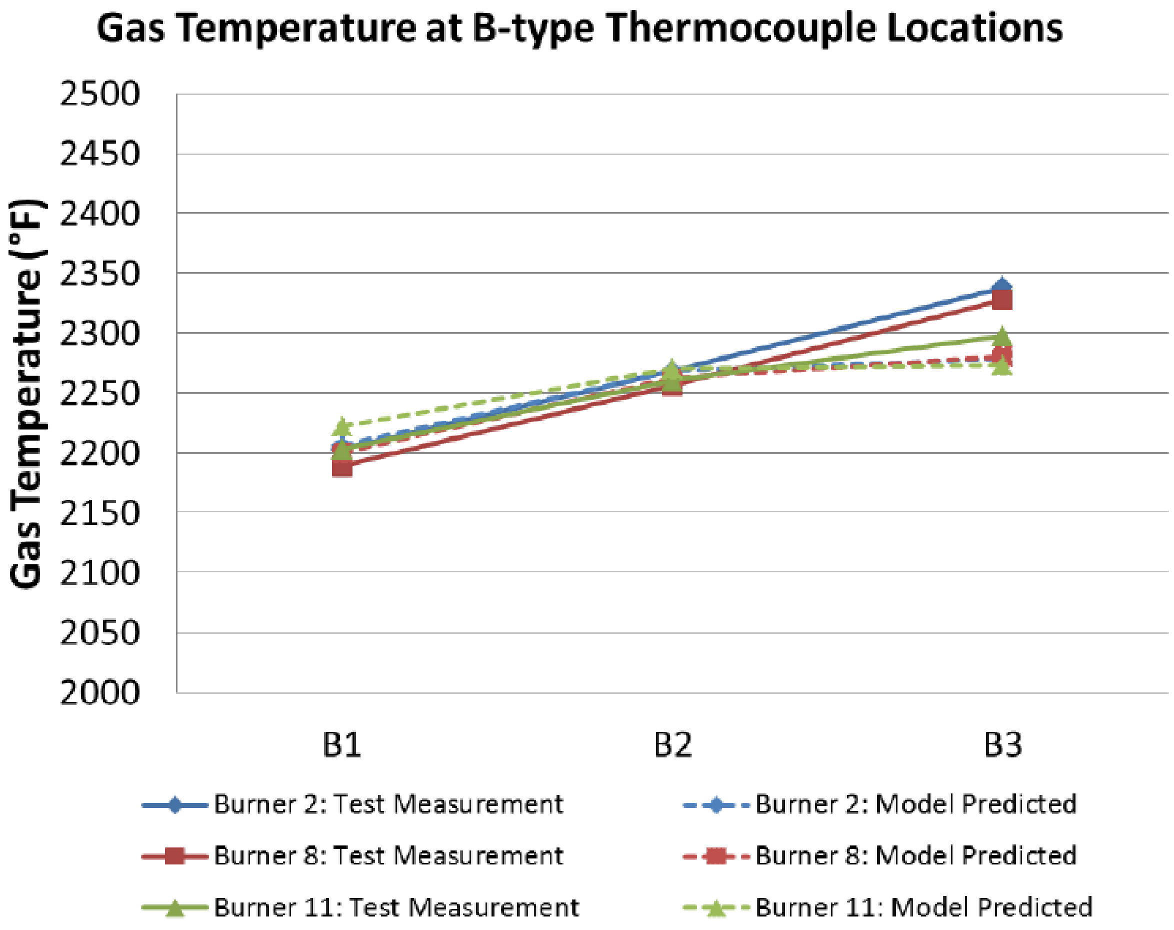
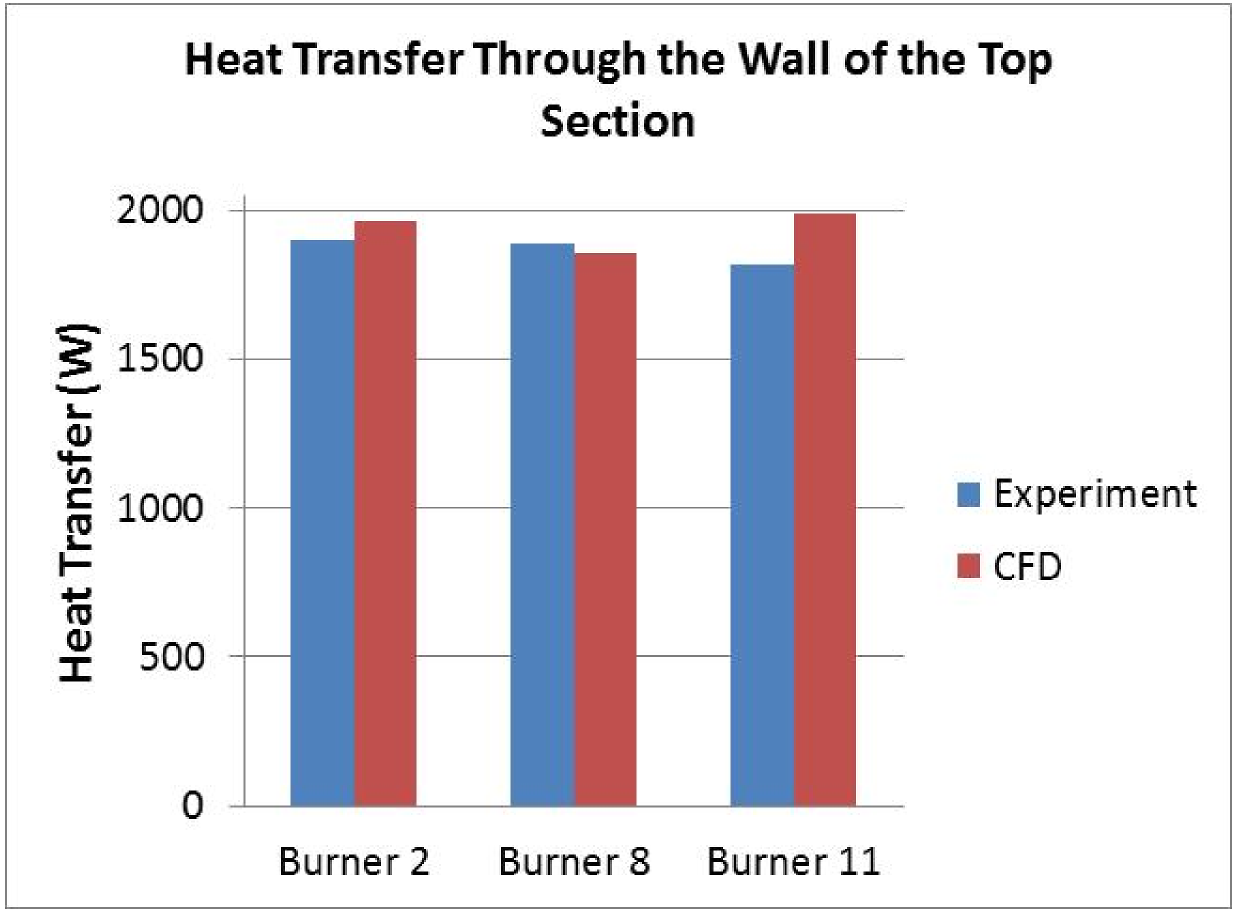
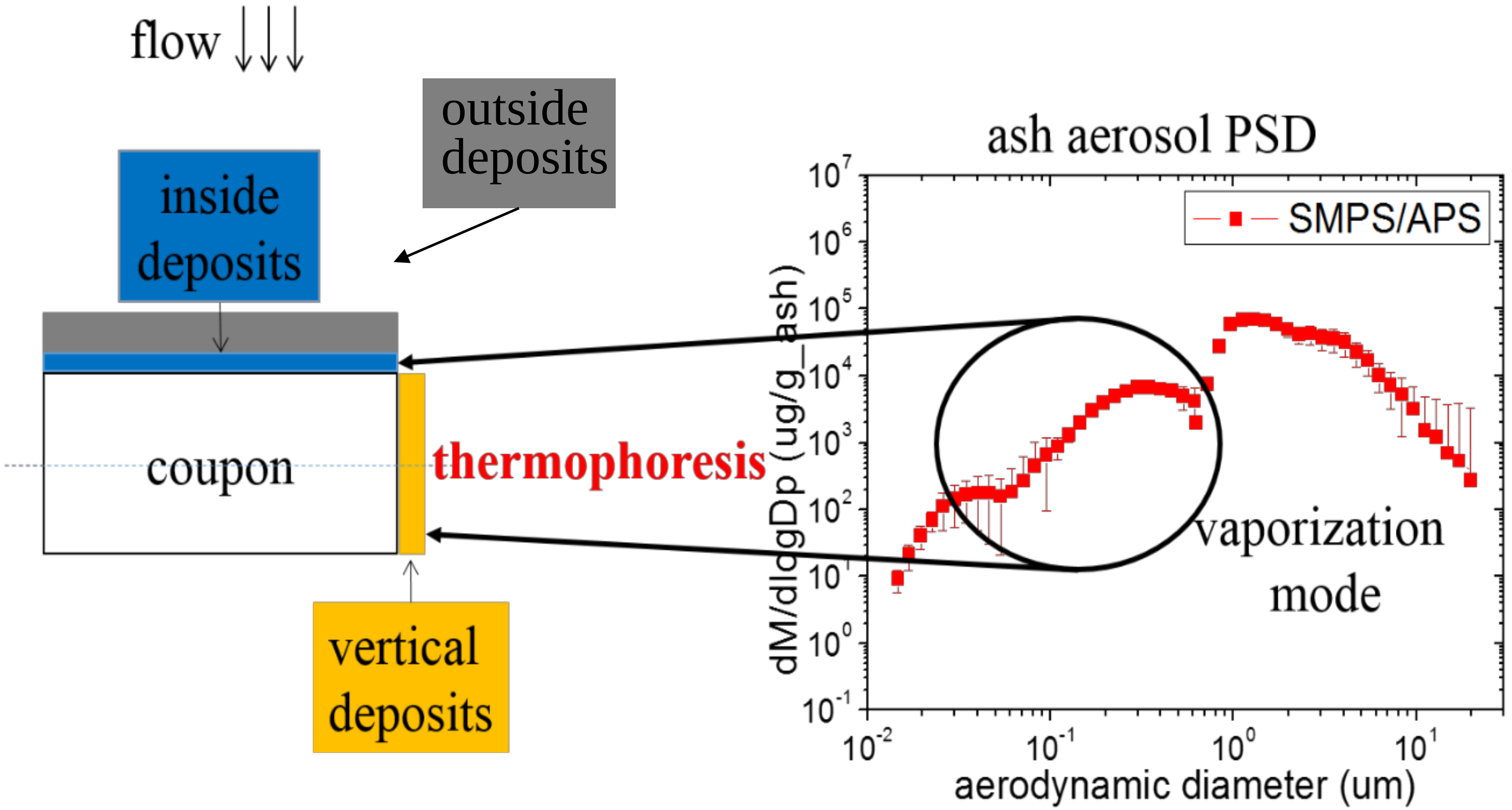
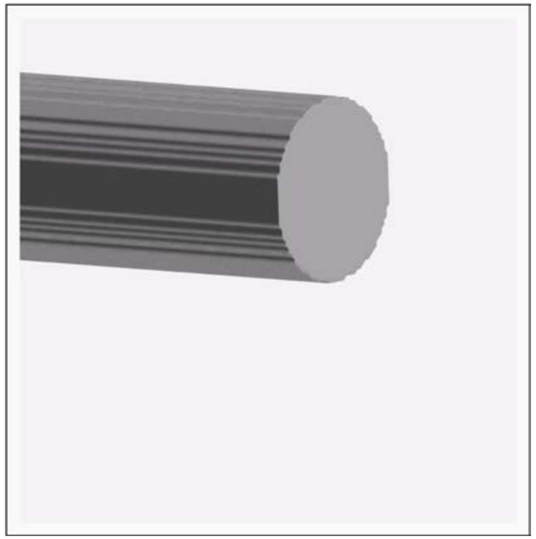


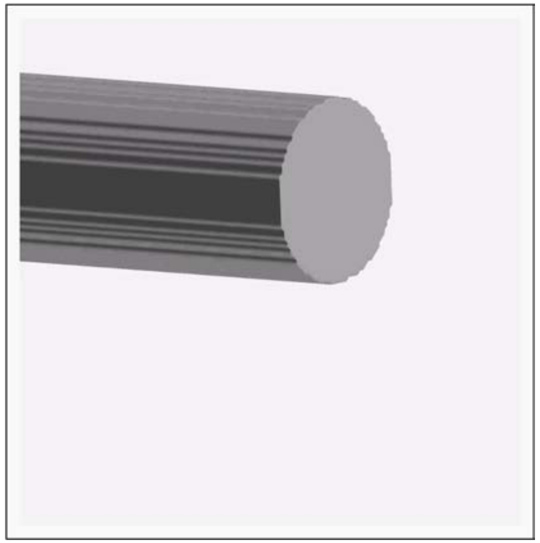


K-type thermocouples located in the top section (3 flush with the inside wall, 3 at the midpoint between the inside wall and outside shell).

Ash aerosol PSD and deposits (vertical, inside and outside)





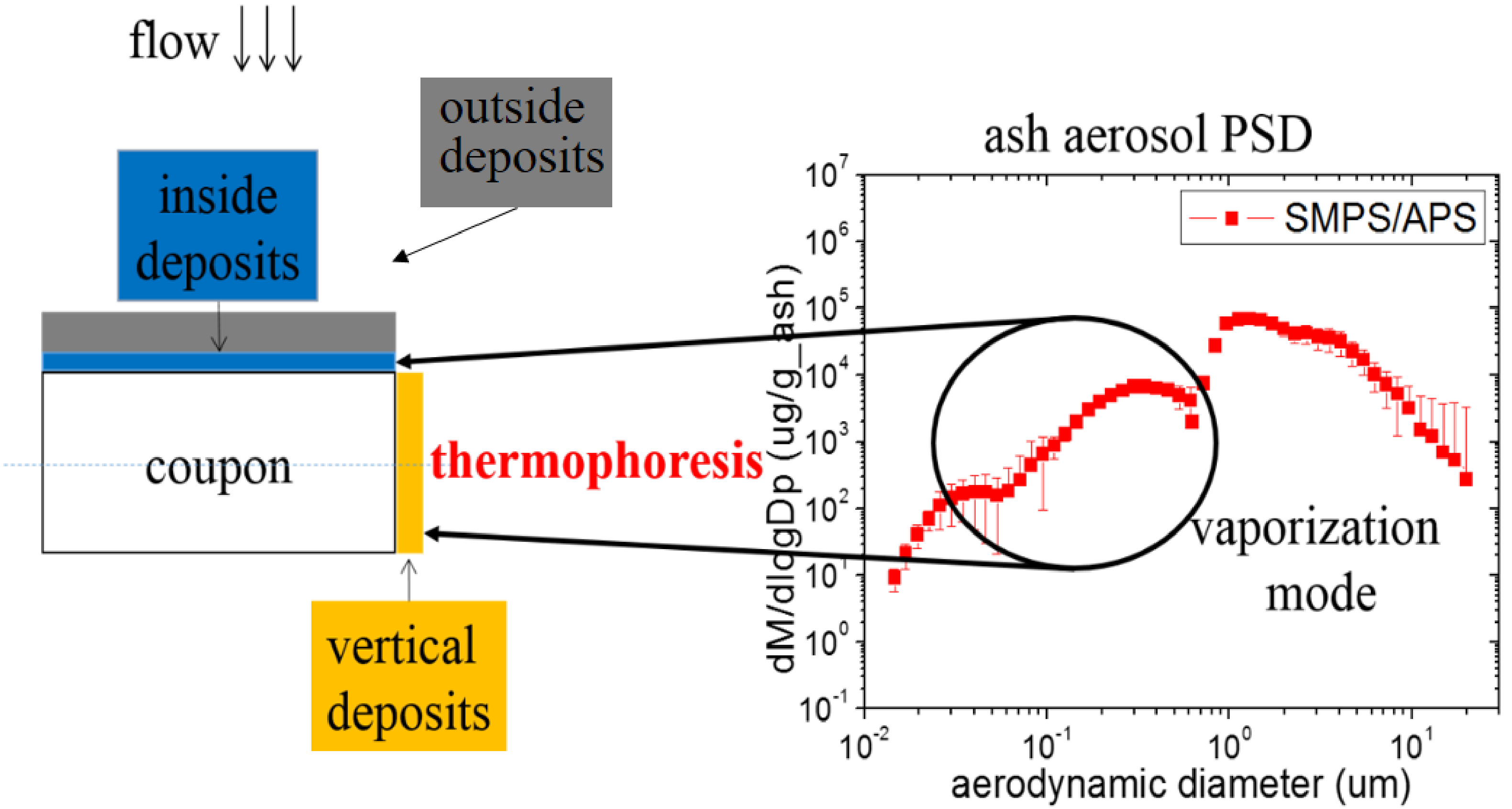


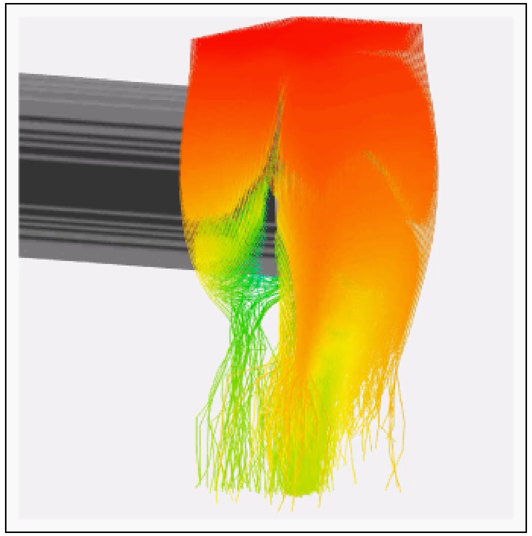
Horizontal deposits:

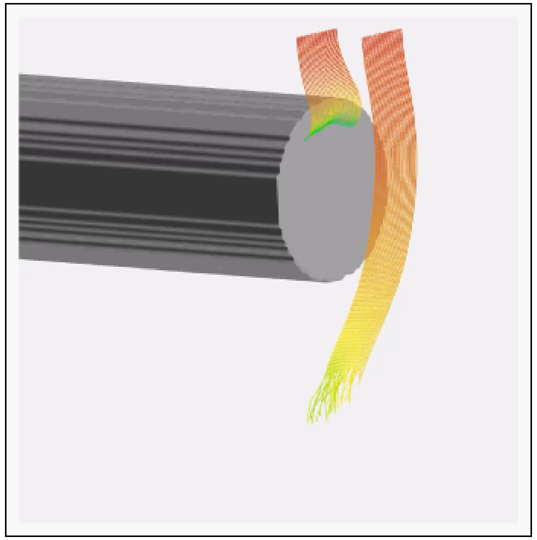
Outside deposits: loosely bound, easily removed by vigorous shaking.

Inside deposits: tightly bound, removed only by scraping.

Ash aerosol PSD and deposits (vertical, inside and outside)







Horizontal deposits:

Outside deposits: loosely bound, easily removed by vigorous shaking.

Inside deposits: tightly bound, removed only by scraping.

1.5 MW CFD-Based Burner Design

Pulverized Coal Combustor (L1500)

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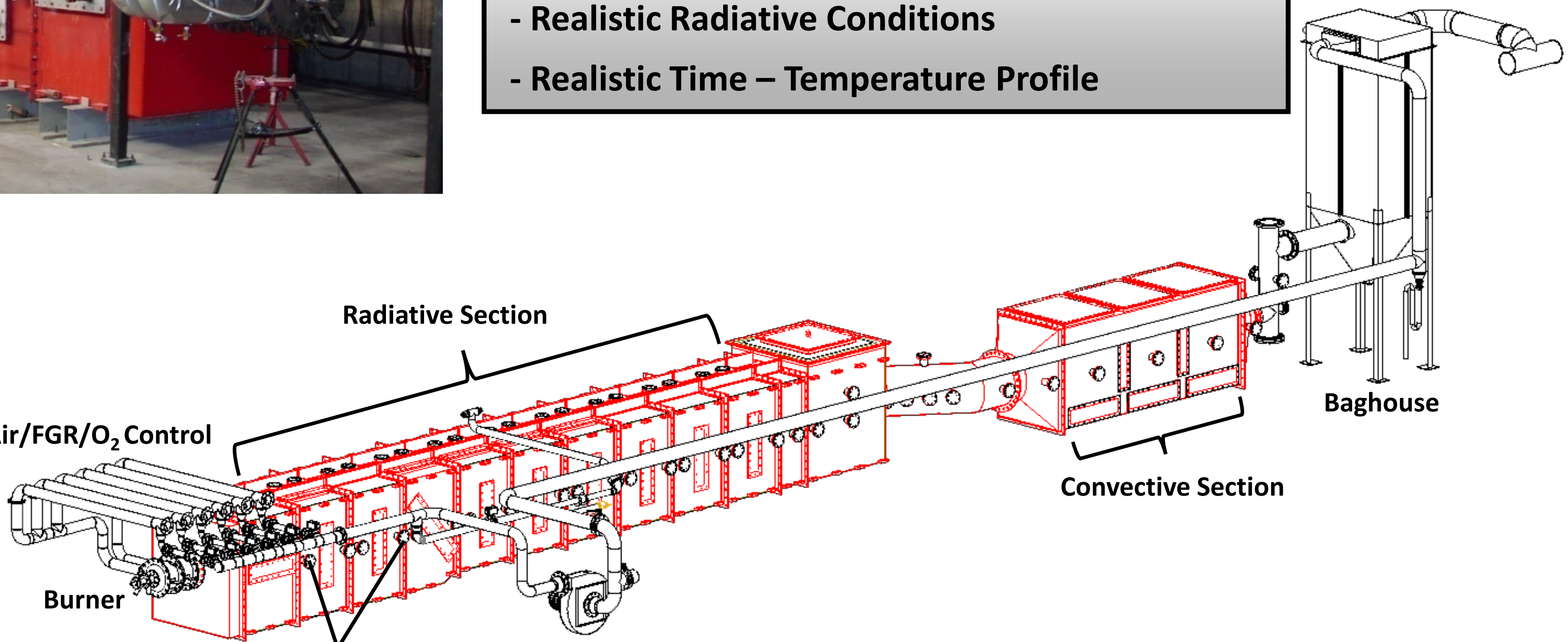
Unique L1500 Capabilities:

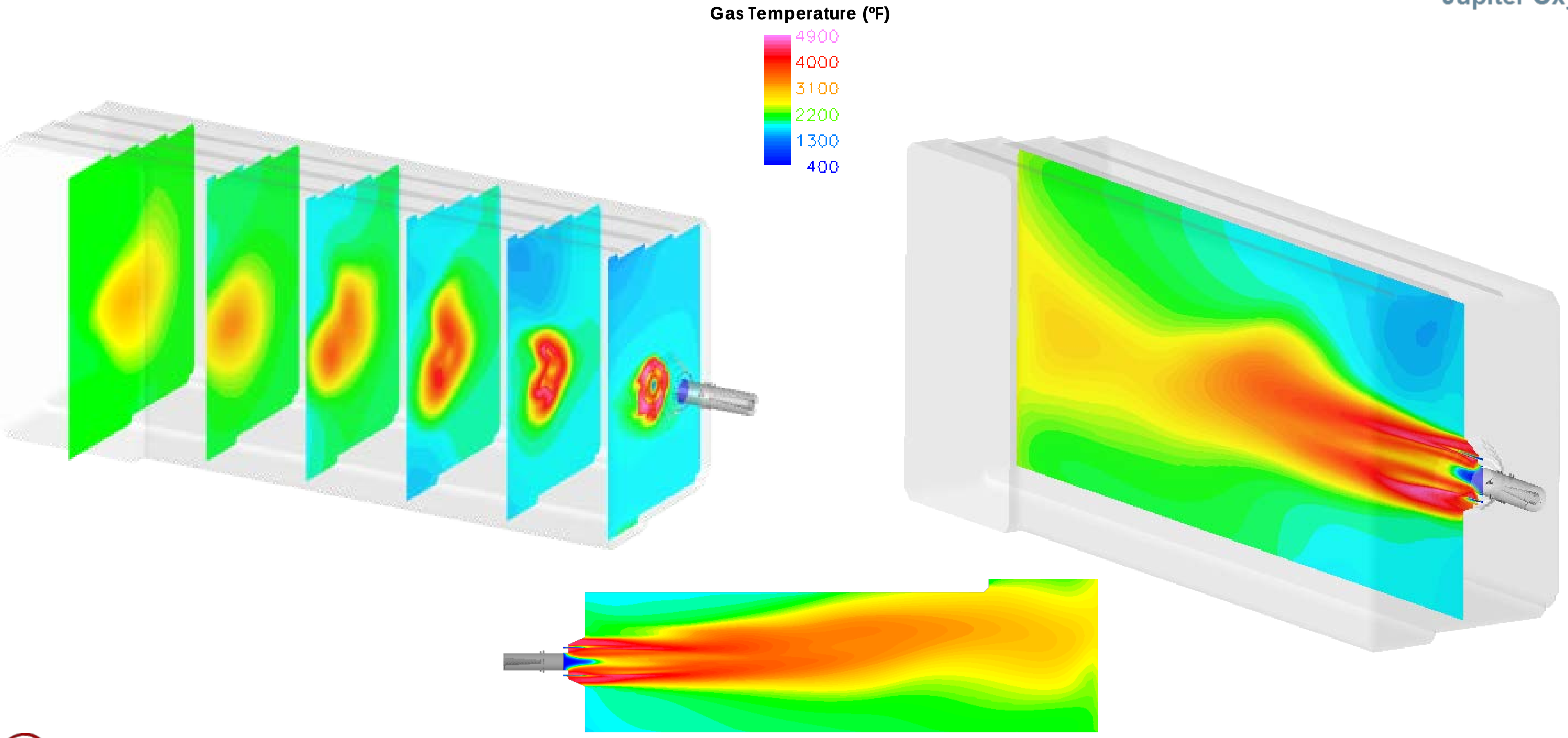
- Realistic Burner Turbulent Mixing Scale
- Realistic Radiative Conditions
- Realistic Time – Temperature Profile



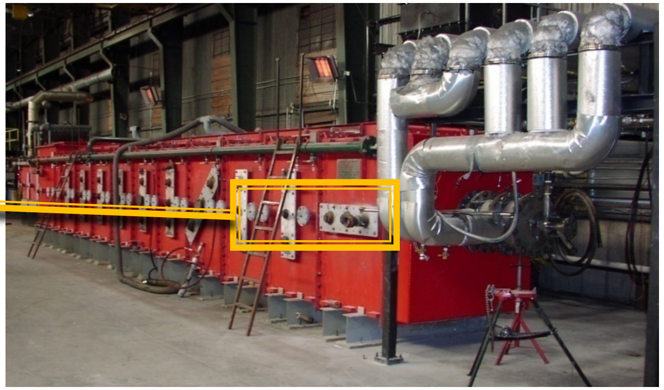
Leveraging Strengths of Project Partners

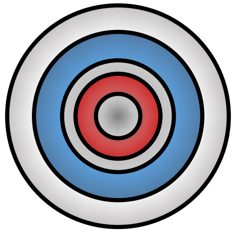
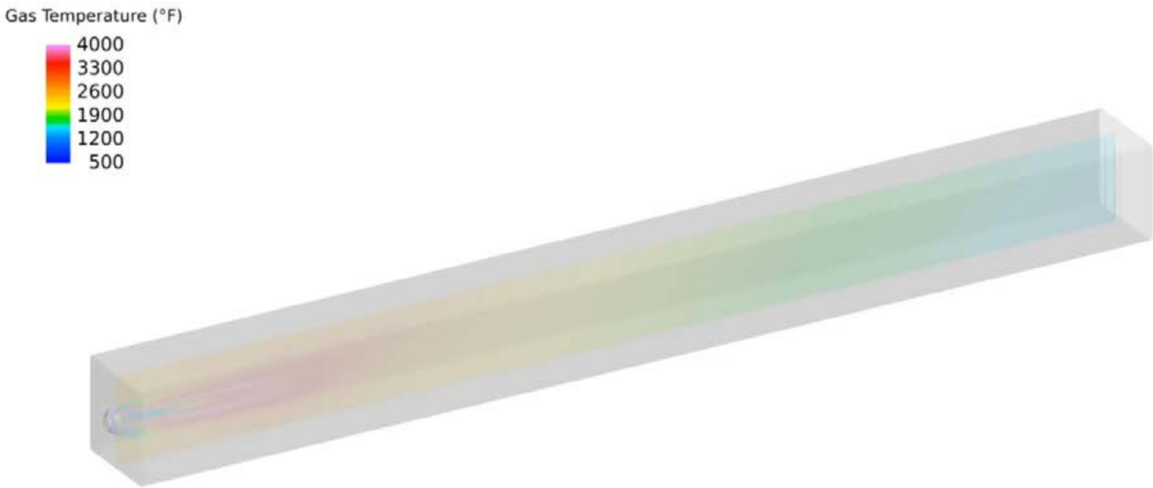
Jupiter Oxygen Corporation High Temperature Oxy-Combustion

Jupiter Oxygen



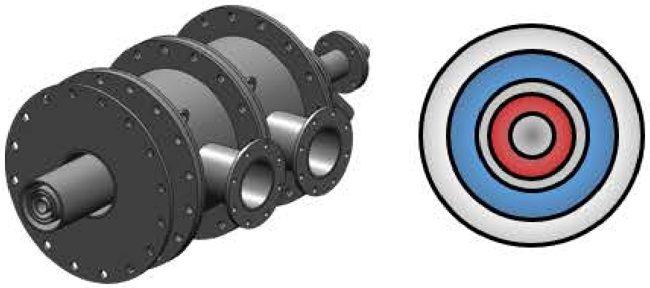
High Temperature Oxy-Coal Combustion
Atmospheric Pressure

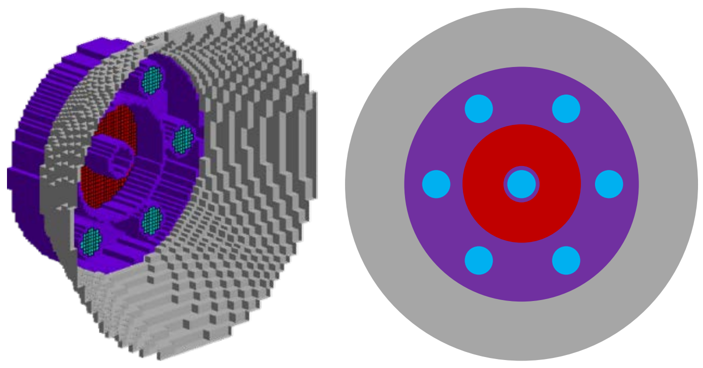
High Temperature Oxy-Coal Combustion

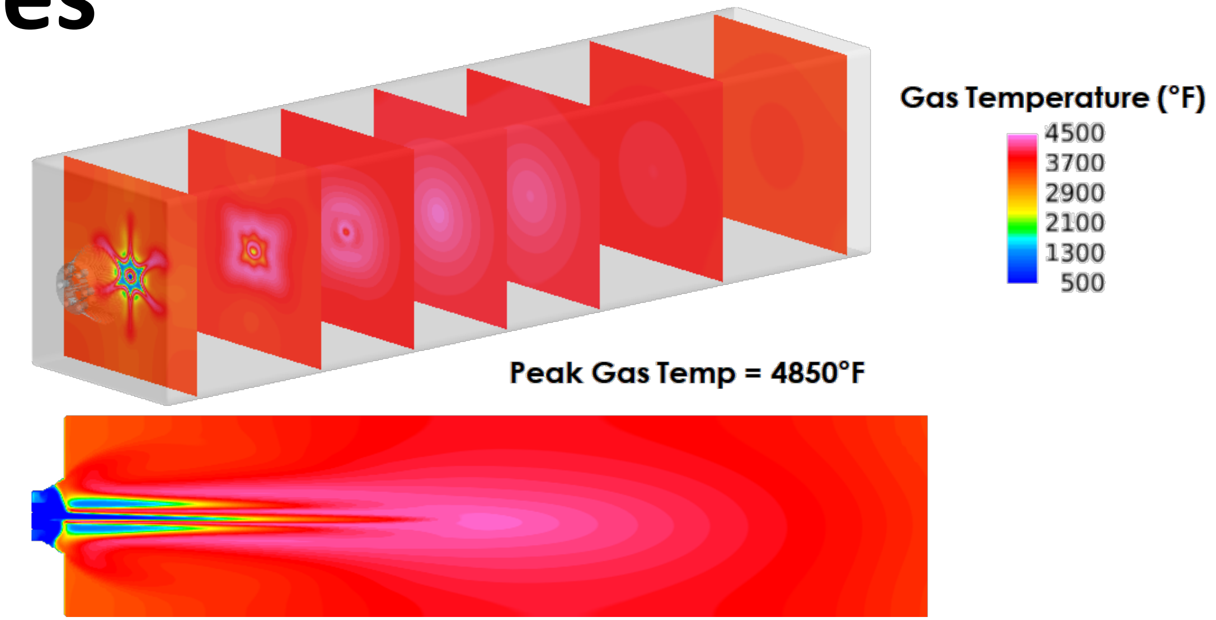
Atmospheric Pressure



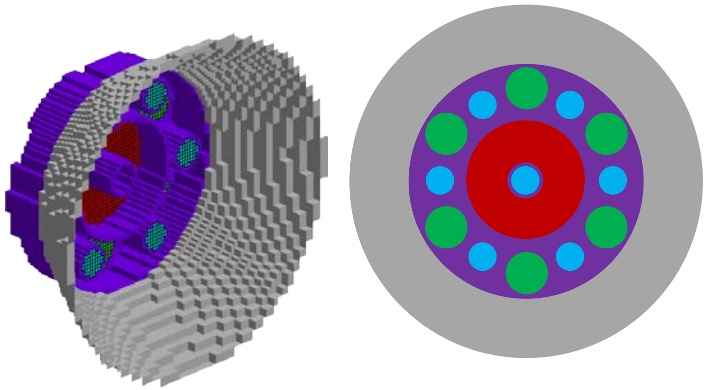
HT Oxy-Coal at Large Scales

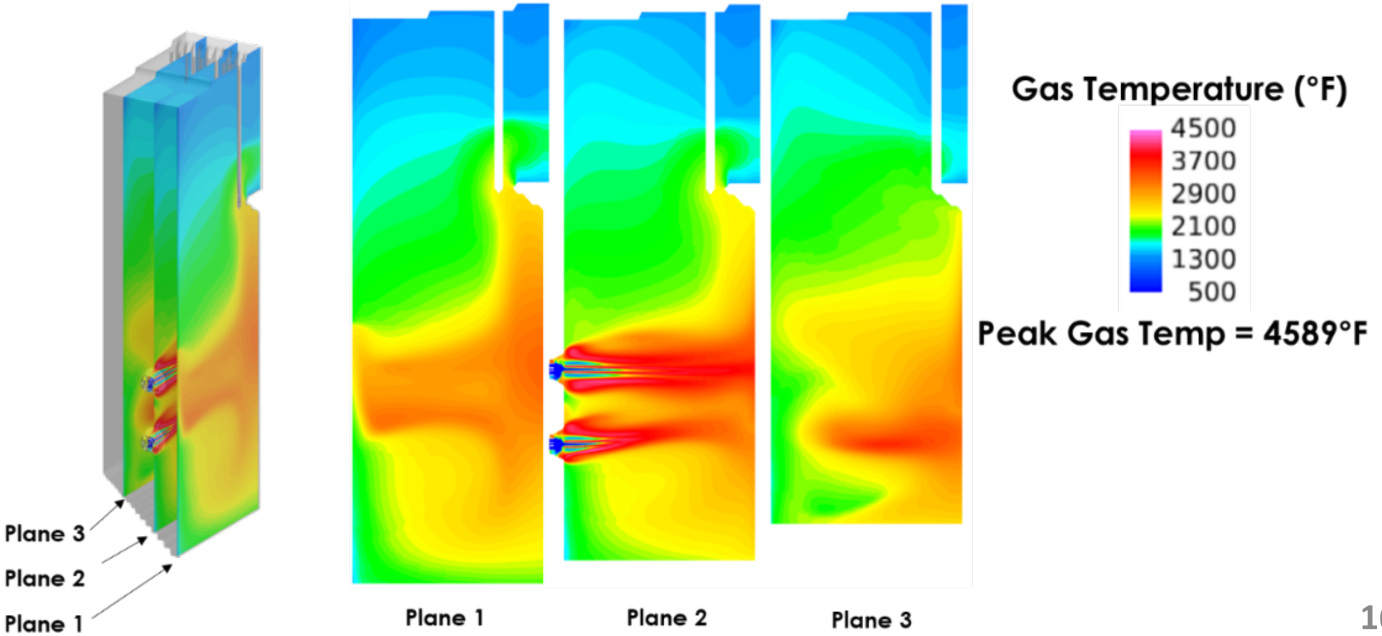
1) 30 MW





2) 120 MW

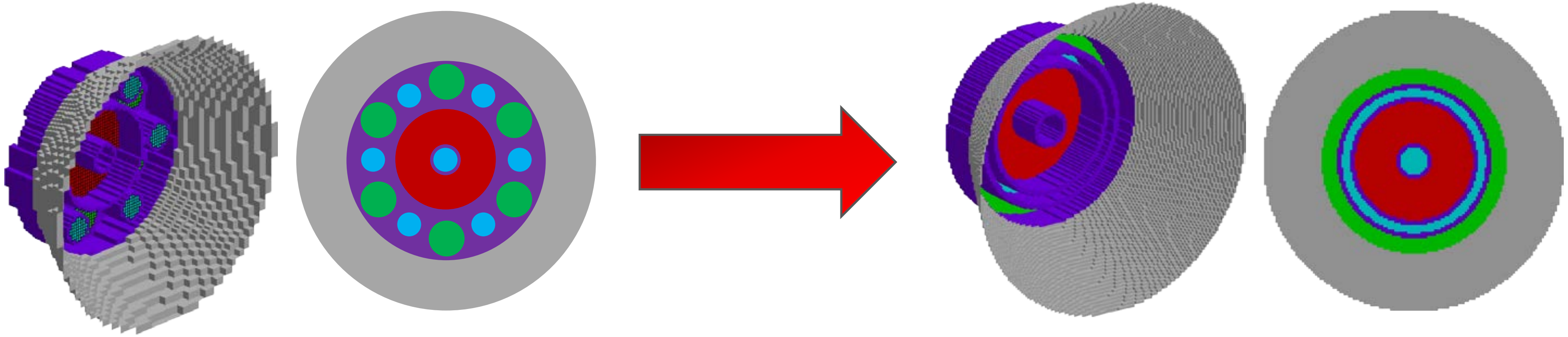




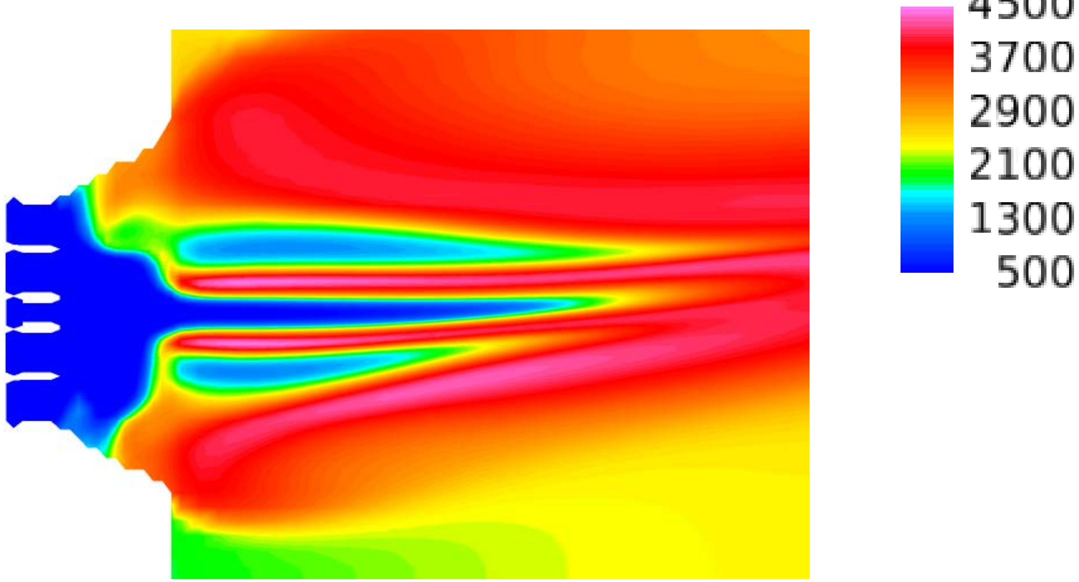
HT Oxy-Coal at Large Scales

Moderating High Radiant Flux

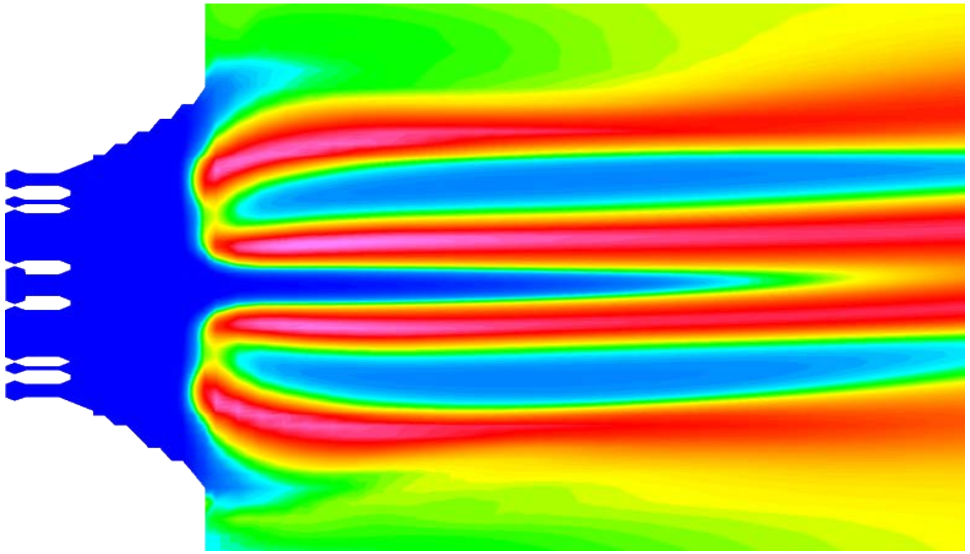
2) 120 MW



Gas Temperature (°F)



Discrete Ports Burner
Peak: 4581°F

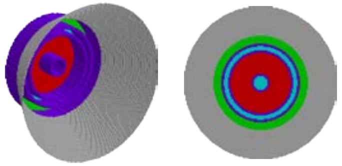


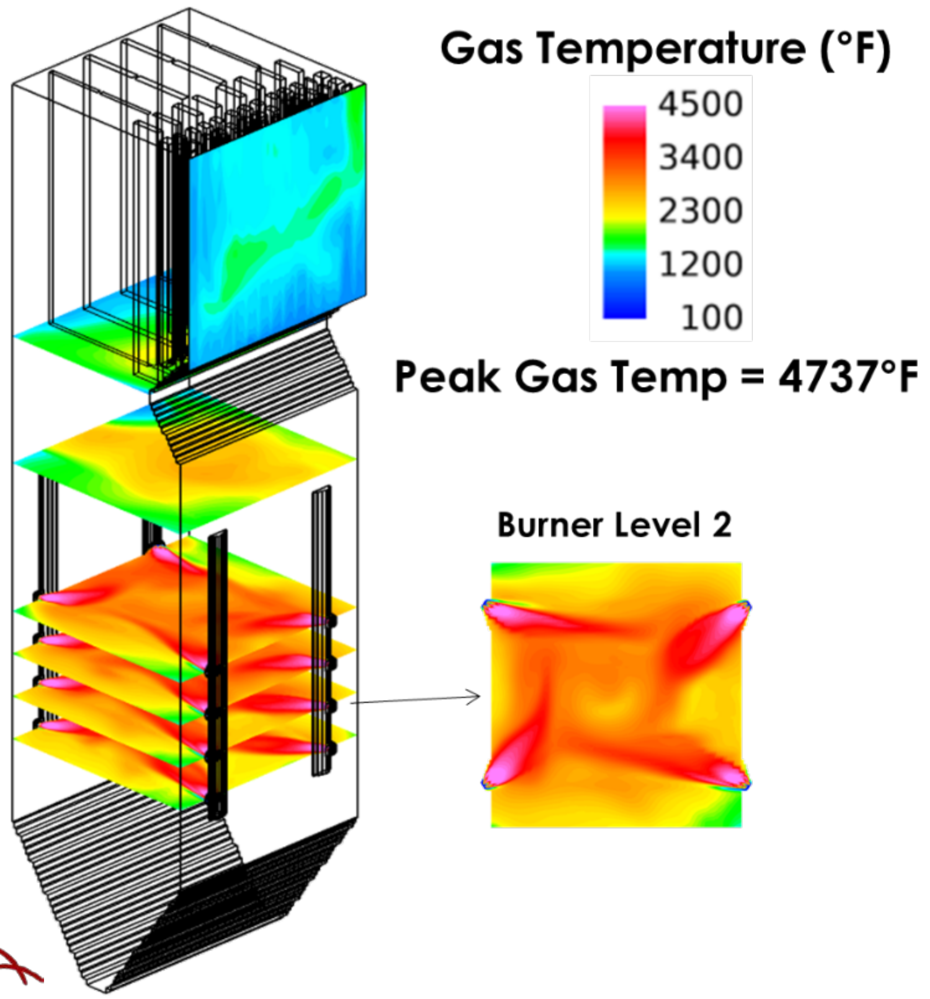
Annular Burner
Peak: 4572°F

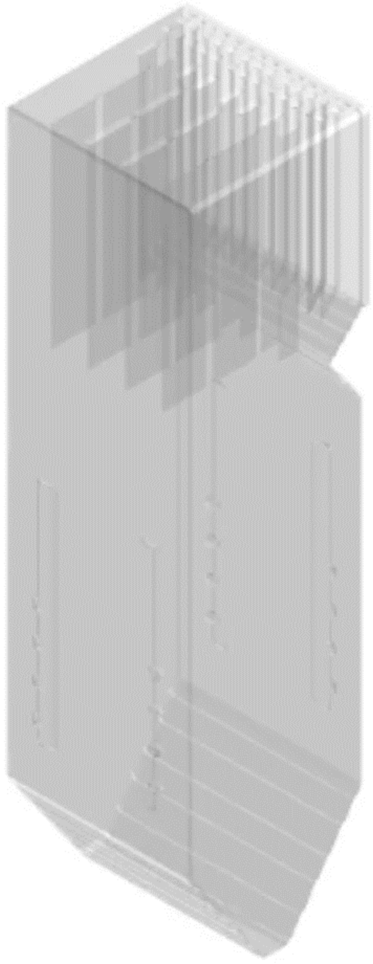
HT Oxy-Coal at Large Scales

Model Predictions of a Novel Approach

3) 960 MW

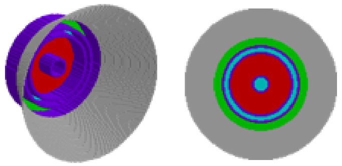


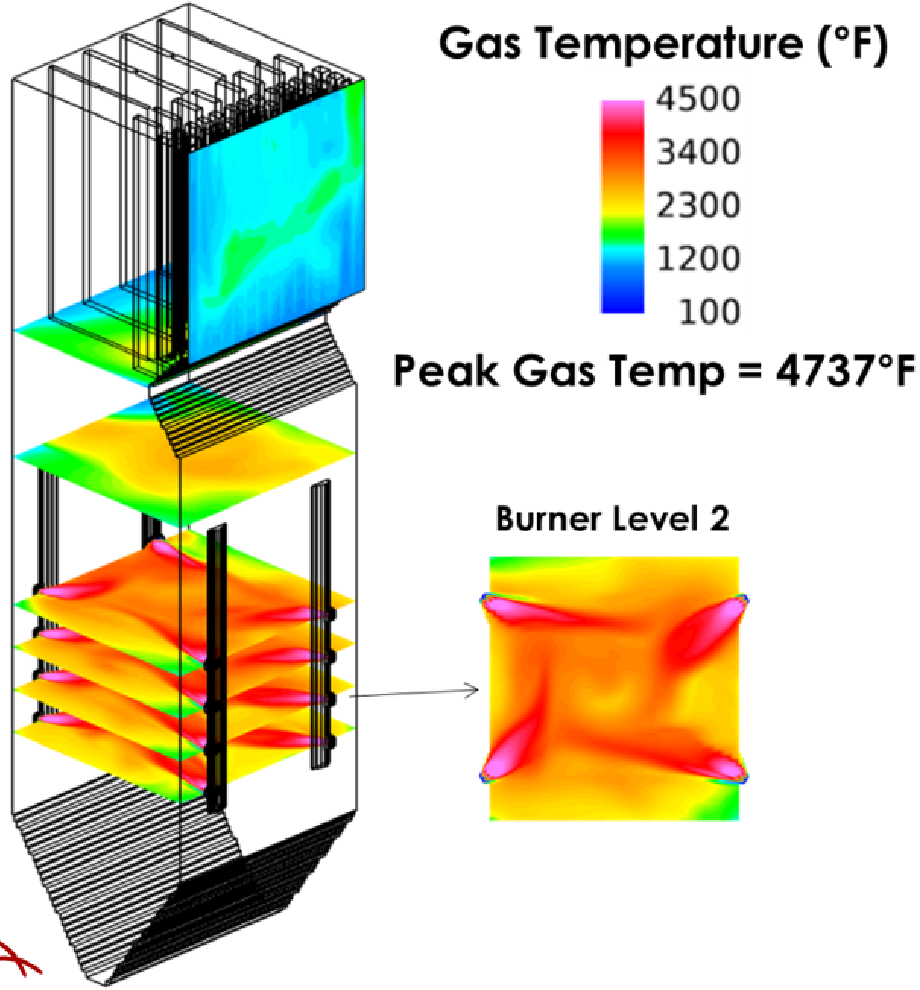


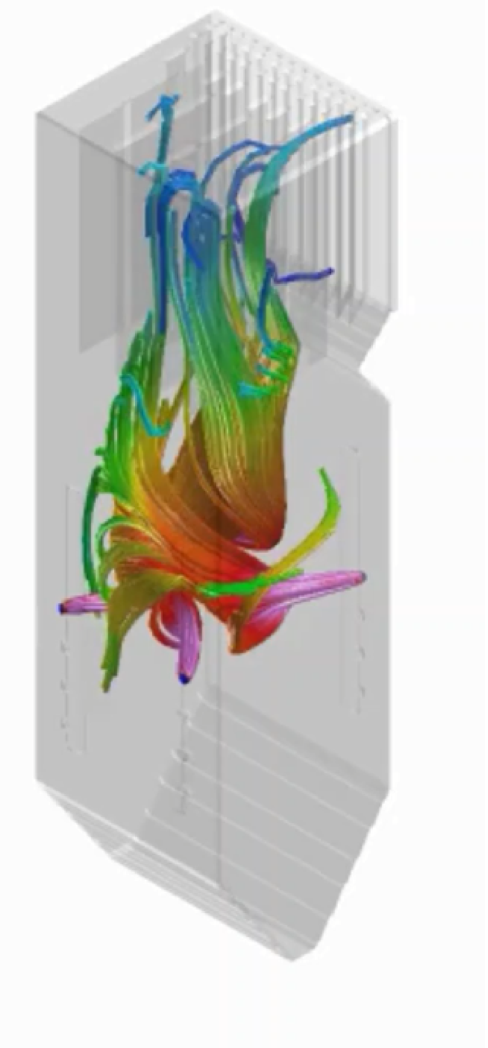


HT Oxy-Coal at Large Scales

Model Predictions of a Novel Approach

3) 960 MW 



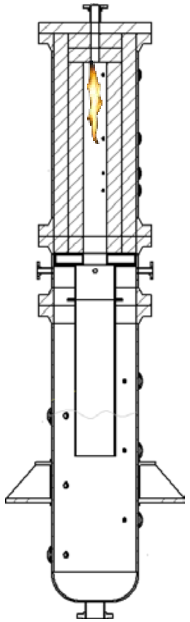


Oxy Coal Combustion at High Pressure

Conduct experiments at University of Utah's Entrained Flow Pressurized Reactor

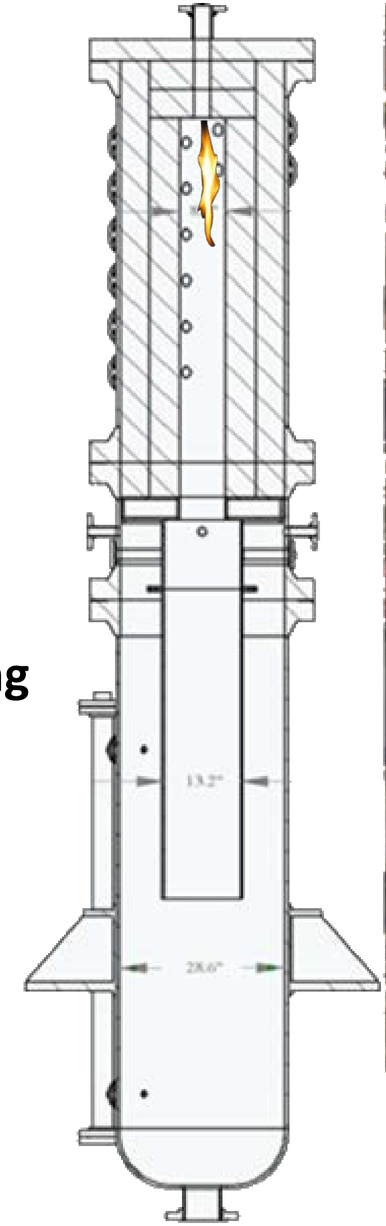
Validate simulations of high pressure

300 kW Entrained Flow Pressurized Reactor (EFPR)



300 kW Entrained Flow Pressurized Reactor (EFPR)

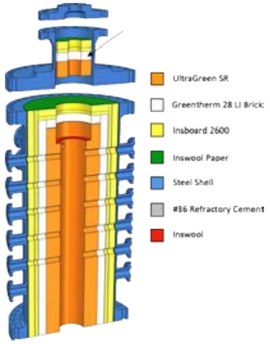
- Converted from entrained flow gasifier
- 300 kW (rated) pilot scale
- Max pressure 450 psi
- Coal-water slurry and dry feeding with pure O_2
- Down-fired, self-sustained and no external heating



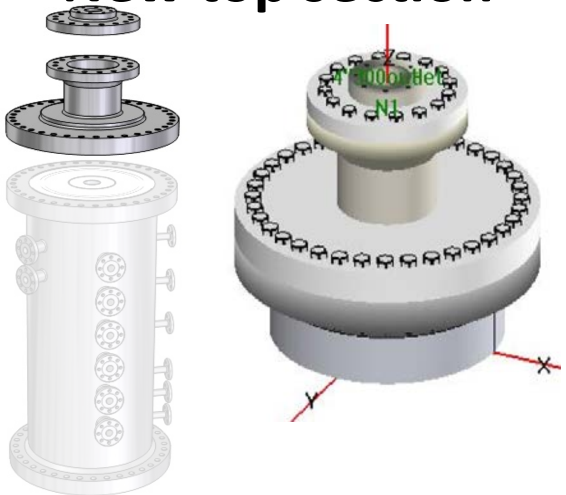
Conversion from Gasifier to Combustor

Hardware and Instrumentation

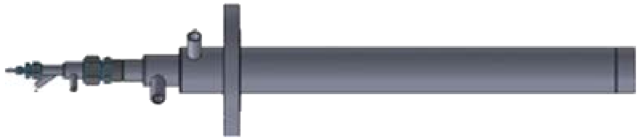
Refractory overhaul



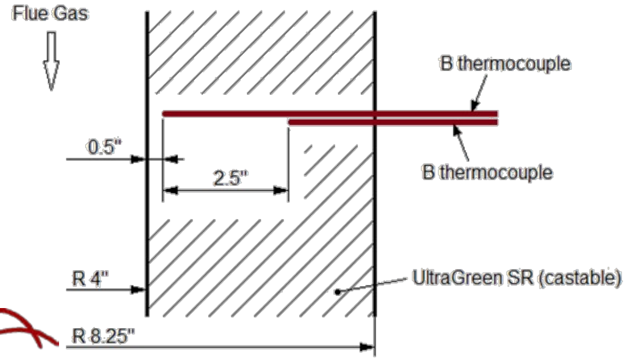
New top section



New slurry injector

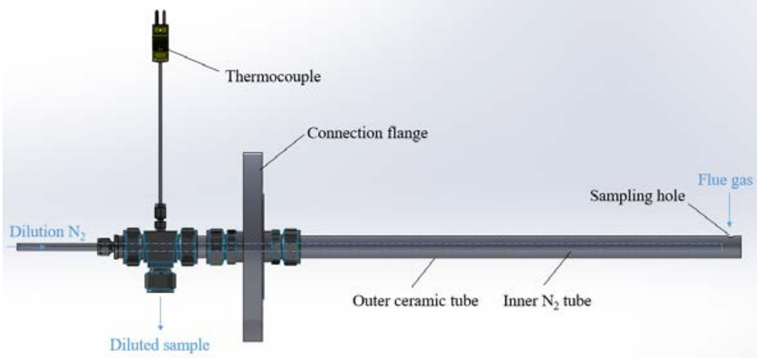


New radiometers & Multi-depth thermocouples

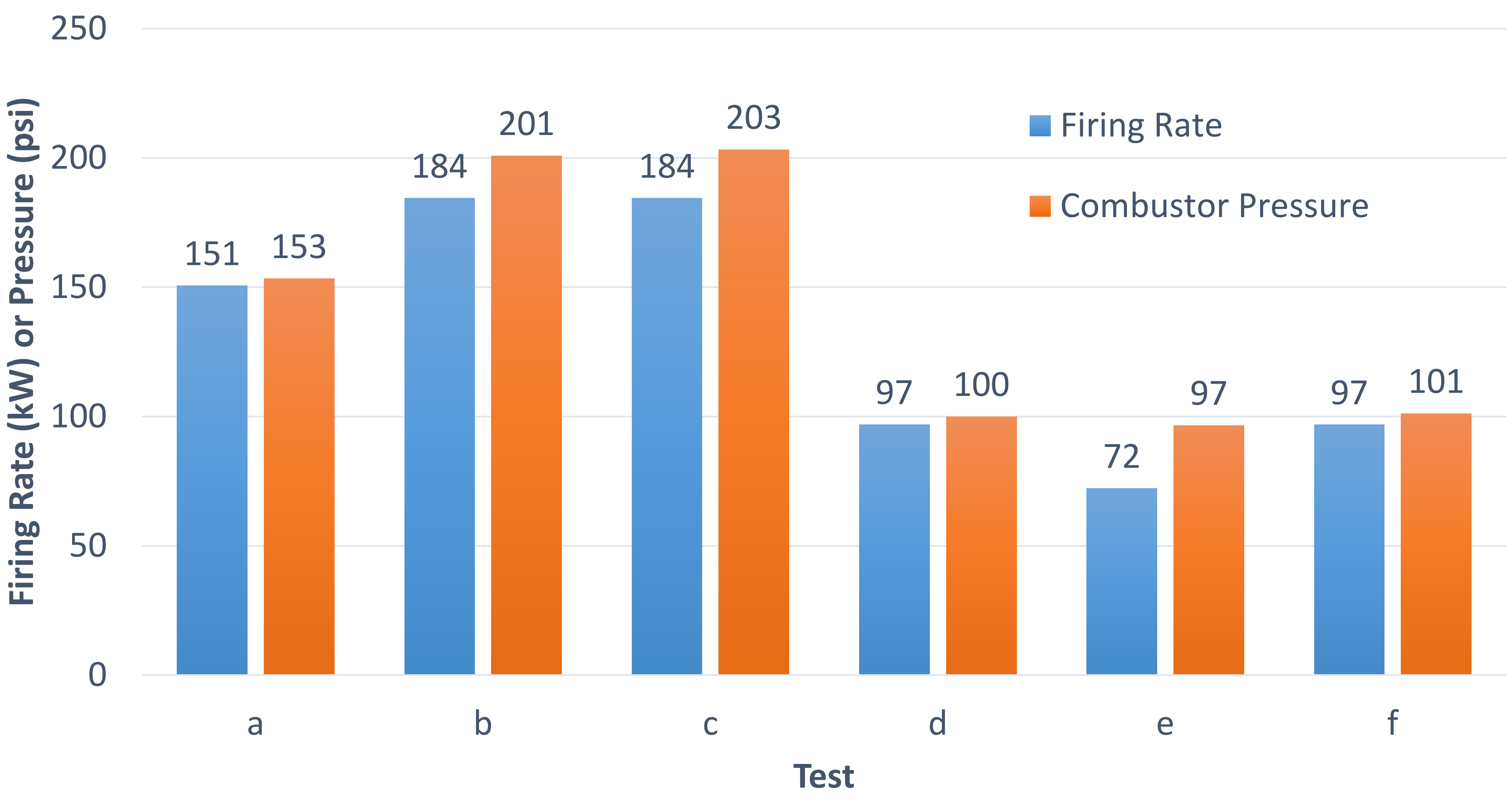


Upgraded gas sampling system

Particle sampling system designed and constructed



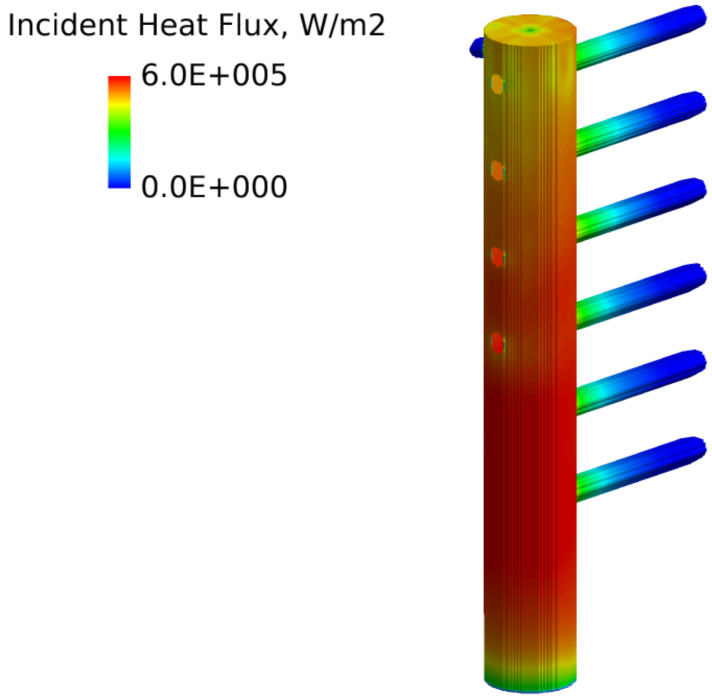
Operating Conditions
High Pressure Oxy-Coal with Coal Slurry Feed

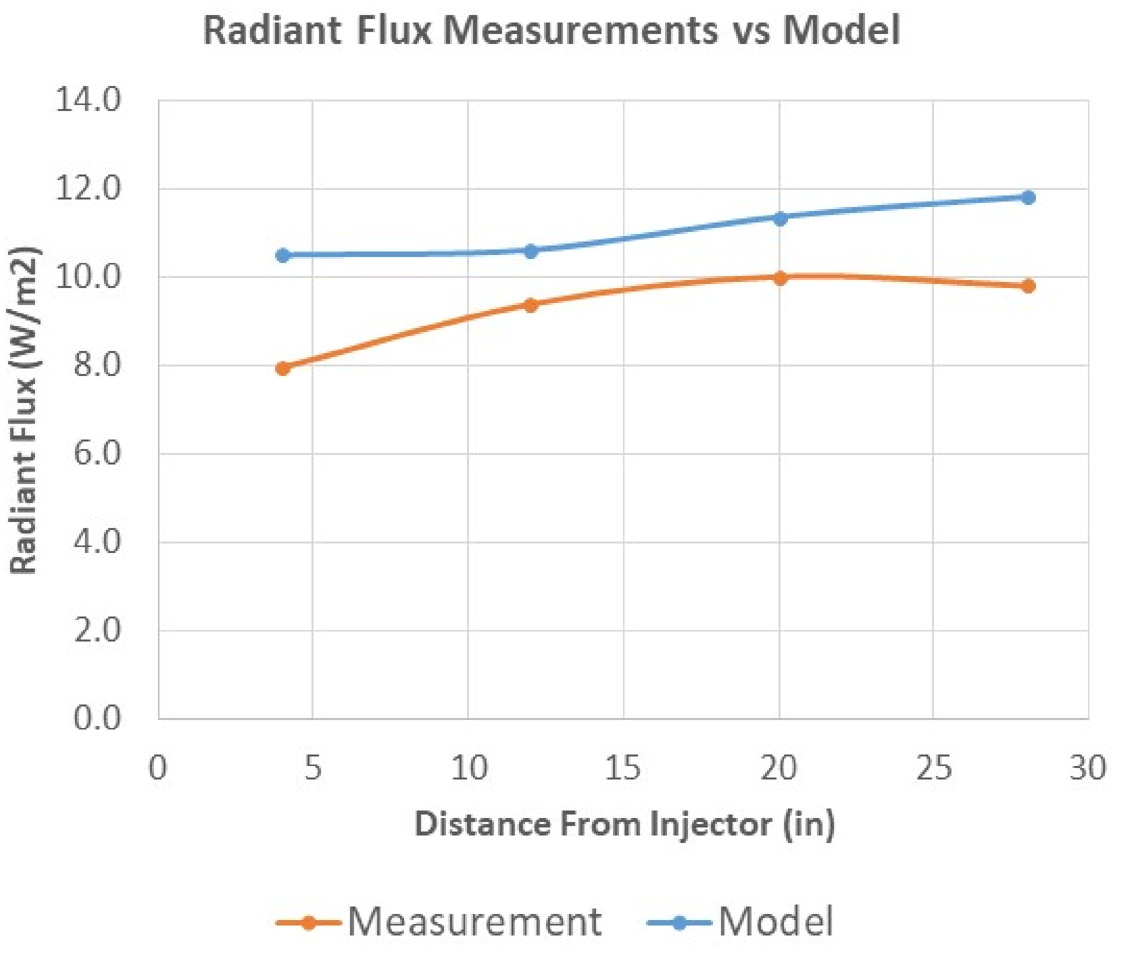


Comparison of Radiometer Measurements and Model

184 kW, 201 psi

- Radiometer post-processor for combustion model
  - Integrates model narrow view radiation flux over field of view of the sensor from the model combustion fields

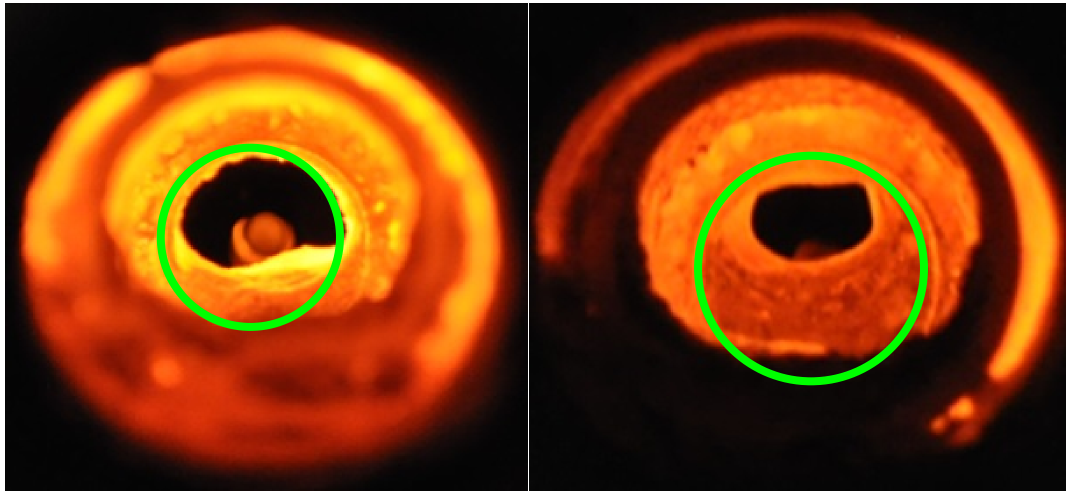




Operational Challenges

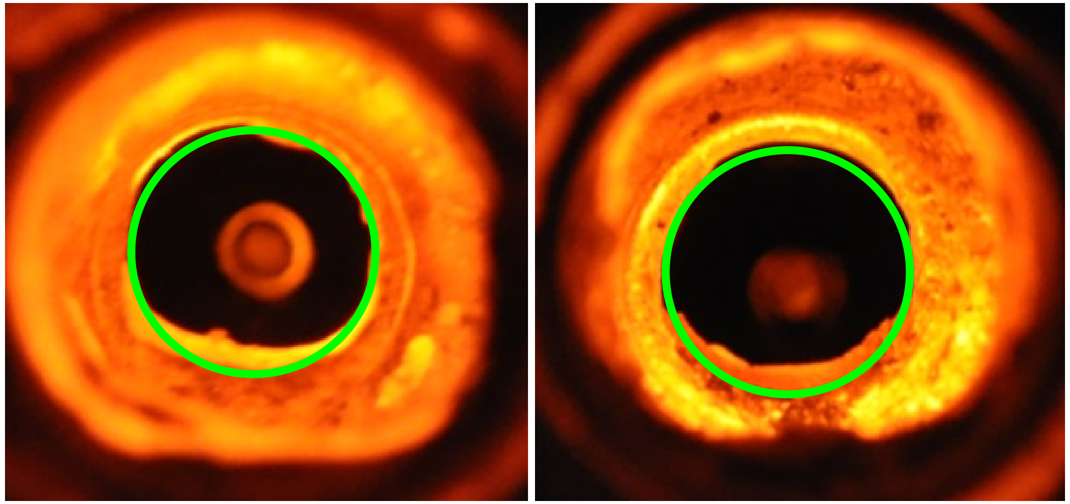
Slag in the Radiometer Ports

Before test



Green circles show the area that should be open

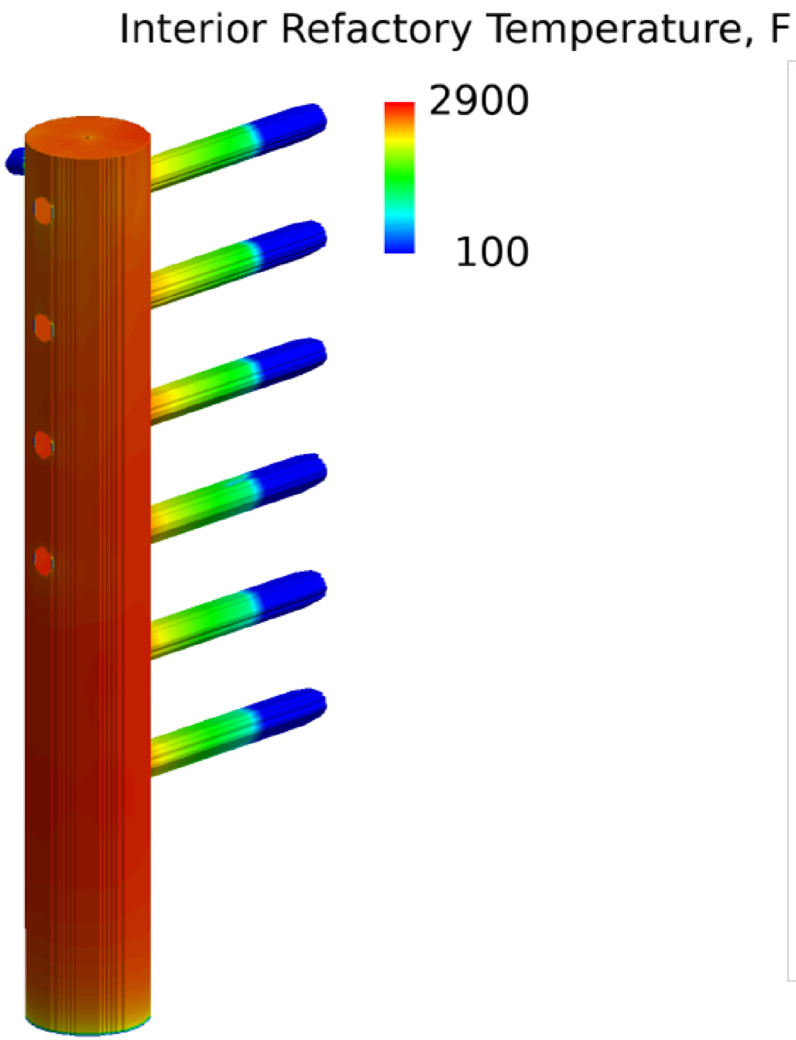
Unacceptable

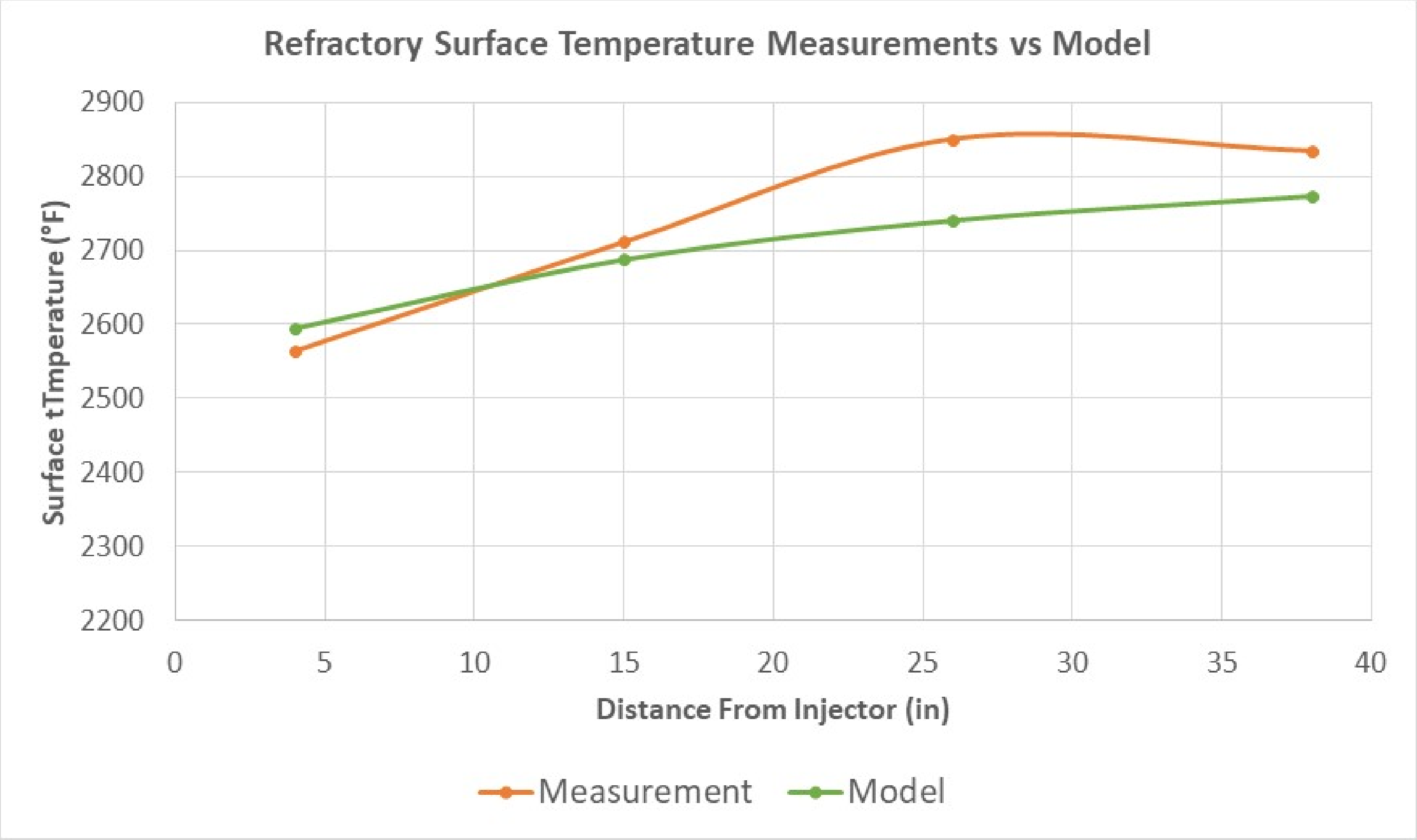


Performance unaffected

Interior Surface Temperature

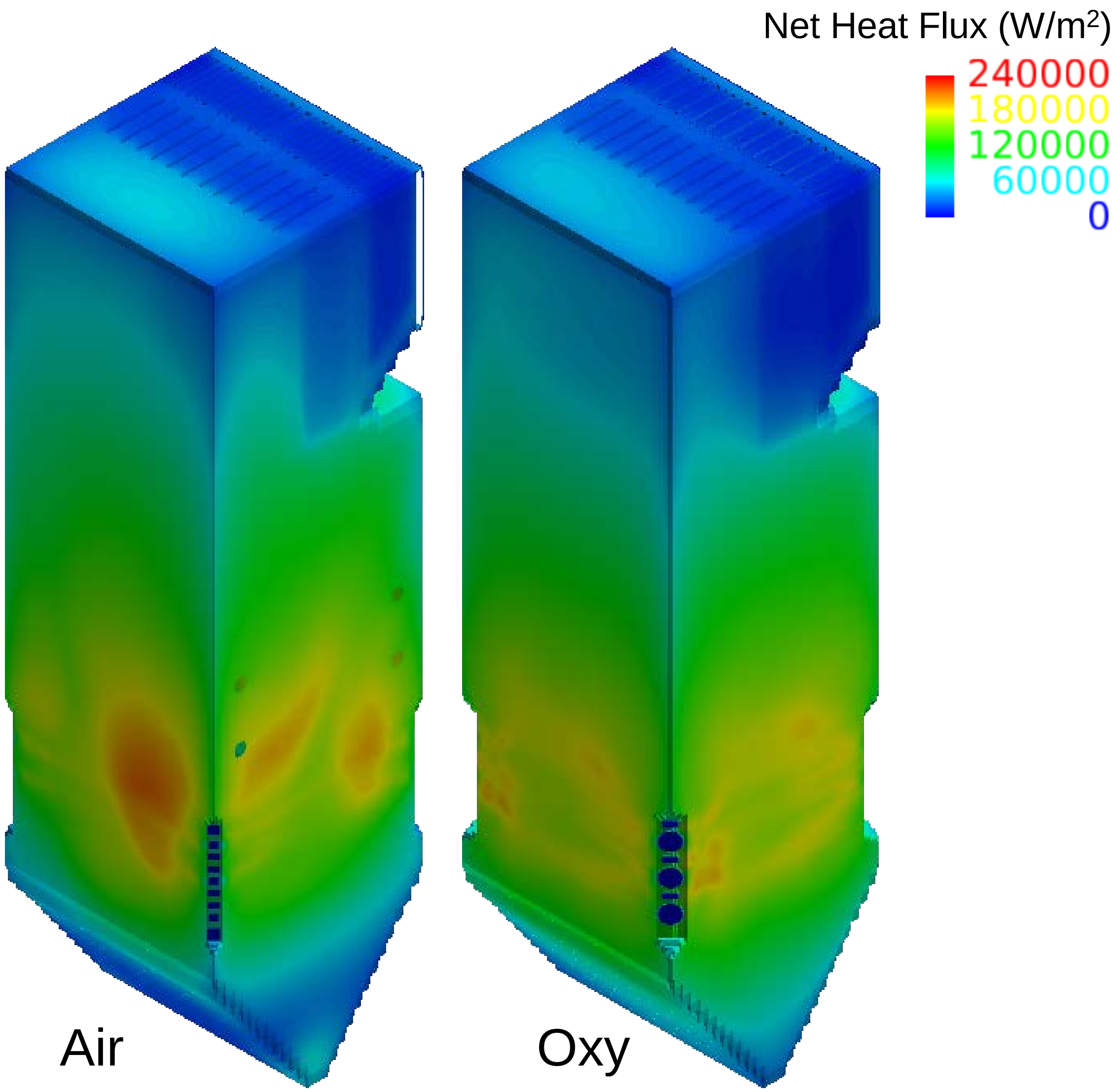
184 kW, 201 psi





Continuing Technology Development/Commercialization

- Dry Coal Feeding in High Pressure Oxy-Coal Combustion Systems (DOE)
- Jupiter Oxygen oxy-coal retrofit for Enhanced Coal Bed Methane in China



Summary

- Approach developed for modeling larger scale systems include quantifying radiant heat fluxes on near-flame components and adjusting design concepts accordingly
- University of Utah's 300 kW Entrained Flow Gasifier has been converted to a high pressure entrained flow combustor along with significant upgrades to reactor hardware and instrumentation
- Annular burner design produces an elongated heat release profile while still producing peak temperatures above 4500 °F
- High pressure oxy-coal combustion experiments have been completed with a coal-slurry feed
- CFD model predictions of radiant heat flux and refractory surface temperatures show good agreement with measurements
- Unique data collection involving size segregated composition of coal ash aerosol at high pressures
- Full-scale burner design evaluation has resulted in highly successful full-scale implementation; working with Honeywell on commercial version

Acknowledgment

This material is based upon work supported by the Department of Energy under Cooperative Agreement No. DE-FE0025168.

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